A T H E S I S

on

THE ALTERNATING SINUSOIDAL CURRENT;

ITS PHYSICAL CHARACTERISTICS AND THE PHYSIOLOGICAL AND THERAPEUTIC RESULTS OF ITS APPLICATION BY MEANS OF THE BATH.

by

A. DINGWALL - FORDYCE, M.B., Ch.B. 1898.

THE ALTERNATING SINUSOIDAL CURRENT;

ITS PHYSICAL CHARACTERISTICS AND THE PHYSIOLOGICAL AND THERAPEUTIC RESULTS OF ITS APPLICATION BY MEANS OF THE BATH.

The subject of Physical Science is one which has even since remote ages before the birth of Christ compelled the attention and attracted the notice of thinking men in all parts of the world. Till within very recent date, however, the foundations of our knowledge respecting it have been but unstable and uncertain, and while, within the last few years, great and unprecedented strides have been made in the subject, they have in all cases mainly served merely to demonstrate the extent of our ignorance, and, in some few cases, have further proved that what had been considered a corner-stone of our knowledge was after all but an erroneous conception. But on no one branch of the subject has more light been thrown than on that of electricity. The study of the properties of the electric current has, within recent years, been followed by an enormously increased number of scientific men and the fruits of their researches, while as yet in many cases inconclusive and uncertain, have a very special interest for the Practitioner in Medicine. Scientific and laboratory experiments and examinations have served to place at the disposal of medical men agencies hitherto unsuspected and unknown, of immense power and infinite possibilities for use or abuse. The discovery of these gigantic natural powers evolved from and originating in laboratory experiments opens up to the practical physician new avenues of medical examination and treatment, but before they can be relegated to their own proper position among the other remedies at his hand require from him much careful observation of their practical effects.

One such agency is that which forms the subject of this paper, a youthful shoot from the great tree of electricity, as yet unranked among its elder sisters. And, as the description of a twig would be wholly incomplete without some general outline of the characteristics of its mother tree, I have consequently devoted the first part of my paper to a short general sketch of the physical characteristics of an electric current, followed by the main known facts as regards its physiological effects.

I then take up the subject of Electric Baths and so pass on to consideration of the Alternating Sinusoidal Current and the observations I have been enabled to make upon it.

I. ELECTRO-PHYSICS.

Starting with the fundamental axiom that the cosmos of which we form part consists essentially of three component parts - solid, liquid and gaseous matter - we shall recognise that in order to produce motion it is necessary to apply force, the resultant action being designated work.

The definition of the word "energy" may therefore be taken as "the power of doing work".

Of energy there are two types:- (1) kinetic, (2) potential energy and broadly speaking the varieties may be divided into four groups, namely:-

(1) Molar,

(2) Heat,

(3) Chemical, and

(4) Electrical,

each and every one being interchangeable and indestructible.

Now I have mentioned "Electrical" as one of the varieties of energy and in fact electricity, i.e., the supposed cause of electrical phenomena, may be regarded as a form of potential energy.

But what, in their simplest forms, are those electrical phenomena?

They consist essentially in this, - a peculiar reaction, between themselves and also to certain other substances brought within their sphere of influence, of bodies stimulated by friction, this reaction being of such a nature that the two substances rubbed together attract one another, whereas repulsion occurs between an outside object and one of the above after momentary contact has taken place. Further the reaction of such electrified bodies to a third leads to the conclusion that there must of necessity exist two kinds of electricity, and also that bodies charged with similar electricities repel one another, while bodies charged with opposite electricities attract one another.

In other words, "the process of electrification consists in the simultaneous and correlative production of equal quantities of positive and negative electricity". It is important to remember that all bodies do not re-act in the same manner to this process of electrification. Some bodies when electrified at one part are immediately found to be electrified all over and these bodies are called good <u>conductors</u> of electricity, while bodies which do not permit, or only very slowly, the passage of electricity through them are called <u>non-conductors</u> (insulators). <u>Air</u> is a non-conductor; <u>water</u> and <u>aqueous</u>

solutions of soluble salts are good conductors. Thus if two bodies of conducting material be rubbed together and then separated, that one which is non-insulated fails to show readily recognisable signs of electrification owing to the great flow of electricity from it.

The force of attraction existing between two electrified bodies is found also to act on bodies placed between them and tends to force them in either one direction or the other and the extent of the area within which these forces act is called the electric field which, as we have seen before in the statement that "the process of electrification . . . . . and negative electricity", is always bounded by surfaces possessing equal opposite correlative electrifications, wherever those electrifications may be situated. The energy of an electric field is the total amount of work that can be done in it by attraction and repulsion of objects therein and is equal to the energy expended in establishing the field.

Now, by simple experiment, it is found that as the distance between two electrified bodies increases the force between them diminishes and the following law has been enunciated that "the electric force between two small electrified bodies, of which the electrification remains the same, is inversely proportional to the square of the distance between them". (Coulomb's Law).

In dealing with quantities of electricity it now becomes necessary in order to measure it to settle our unit of quantity or unit of electricity.

Coulomb provides us with this.

In his experiments he had naturally to judge the degree of electrification of bodies by the mechanical forces they exert by reason of it. "The unit of force is the force that produces unit acceleration in unit mass, or, using one centimetre as unit of length, one gramme as unit of mass, and one second as unit of time, - that is, the so-called C.G.S. (centimetre-gramme-second) system of units, - the unit of force is one dyne. The C.G.S. unit of electric quantity therefore is that quantity which repels an equal quantity at a distance of one centimetre in air with a force of one dyne. This unit being very small in comparison with the quantities that come into account in many electrical phenomena, another unit, known as the coulomb, equal to three thousand million times the unit just defined is often employed, especially in connection with practical applications".

A further important fact is this, that the force of attraction or repulsion between two bodies electrified to a given degree and at a given distance apart varies according to their connecting medium, that is to say, in treating of the force exerted there always exists a varying co-efficient depending on the properties of the insulating medium wherein the bodies are and this is known as the "dielectric co-efficient".

It seems to be beyond doubt that in addition to the condition of the electrified bodies there is also a condition of stress in the medium occupying the electric field, this consisting in tension at every point, in a direction parallel to that in which an electrified particle at that point would be urged, and of a pressure in all directions at right angles thereto.

The electric density, or, in other words, the average quantity of electricity in each unit of volume of the space, is naturally equal to the total quantity of electricity divided by the volume of the space and can be accurately determined by means of simple instruments, - electroscopes.

Experiments by Cavendish, Faraday and Webb go to prove that there is neither electricity nor electric force within a conductor, or, in other words, that an electric field does not penetrate the surfaces of the Conductors which form its boundaries and thus by means of an electroscope it is found that the electric density within a conductor is zero, while the surface electric density at various points may be obtained.

It has previously been mentioned that there exists in an electric field a condition of stress in that medium and as a graphic representation connected with the electric force between the two electrified bodies one speaks of <u>lines of force</u>. Each line is an imaginary line drawn in the field in such a way that at every point in its course it is tangential to the direction of electric force and these lines are imagined traversing the whole electric field from the positive to the negative boundary.

Since, however, there is no electric force within a conductor, there can be no lines of force within it, and, consequently, if an electrified piece of metal be placed in an electric field it interrupts the lines of force which are each cut into two branches, and as a surface at which lines of force end is negatively electrified, and one from which such lines start is positively electrified, it happens as one would expect that that part of the insulated unelectrified conductor which is presented towards the positive boundary of the field becomes negatively electrified, while that part towards the negative boundary becomes correspondingly positively electrified. This is known as electrification by induction.

The effects of this induction are less distinct with badly conducting substances.

Thus it is evident that in the case of a light body in an electric field electrification by induction precedes attraction and what is really observed is attraction between opposite electric charges.

Now suppose we connect two electrified conductors by means of a long wire - a conductor - we find that the signs of electrification of the one become weaker and of the other stronger till both are the same - that is to say, in a state of electric equilibrium brought about by the flow of electricity from the one to the other.

This electric equilibrium is not due to equality of total charge, nor yet to equality of surface-density, but to a condition known as electric potential. As water flows from a higher level to a lower, and as heat is transferred from a body of higher temperature to that of lower, so electricity passes from a conductor of higher electric potential to that of lower.

Electric potential accordingly corresponds broadly to temperature when dealing with heat, or surface-level when dealing with liquids, and in order to have evidence of the existence of electric force it is necessary to have difference of electric potential, the electric potential at any point, A. exceeding the potential at any other point, B., by an amount equal to the work that would be done by electric force upon a unit of positive electricity transferred from A. to B.

Previously it has been mentioned that the coulomb is usually adopted as the unit of electricity, and here it may be mentioned that differences of potential are expressed in terms of the volt, corresponding to 1/300 of a C.G.S. electrostatic unit of difference of potential.

Where the bounding surfaces of an electric field are formed of conducting materials the potential of each boundary is uniform and the difference of potentials between the boundaries is equal to the product of the distance from one surface to the other, measured along a line of force, (e), into the mean electric intensity along this line ($\overline{F}$), i.e., $V - V' = \overline{F}e$.

The intensity at any point is proportional, other things remaining the same, to the charge of the field (meaning thereby the total quantity of positive electricity upon one boundary, or of negative electricity on the other), and therefore $\overline{F}$. must be proportional to the charge. Consequently, for a given field charge and difference of potentials are proportional to each other and the capacity of the electric field may be defined as "the ratio of the charge of the field to the difference of potentials between its boundaries, and it is numerically equal to the charge required to establish unit difference of potentials between them".

Again, - to estimate the energy of an electric field or amount of work which the electric forces of the field can do during exhaustion of the field.

As before seen this may be stated, taking Q. for the charge, as the transfer of $\frac{1}{2}$ Q. from the negative to the positive boundary, and $-\frac{1}{2}$ Q. from the positive to the negative boundary, and thus taking V. and V' to represent the two potentials, the Work, (W.) may be represented as $W. = \frac{1}{2} Q. (V - V')$.

"When two electric conductors are so placed that their surfaces form the boundaries of a field of relatively great capacity, the arrangement is very frequently spoken of as a condenser".

Naturally, there are several varieties of condenser and a very typical one, and one very frequently employed is that known as the Leyden jar.

"This consists of a glass jar or bottle, coated internally and externally with tinfoil to within a moderate distance of the opening, the rest of the surface being varnished with shellac. A brass rod, terminated by a ball, connected with the inner coating, and passing out through the neck without touching it, enables electrical connection to be made with the inner coating when required. Sometimes the jar is closed at the mouth by a non-conducting lid; in this case the rod is usually supported by being put tight through the lid, and makes contact with the inner coating by means of a flexible spring or a few inches of chain."

The charge, (Q.), of a condenser is, of course, the charge of the electric field which is bounded by its conducting surfaces, it is therefore represented as we have already seen in the case of an electric field by Q. - C. (V - V') when C. stands for capacity.

If the charge is to be great, not only the capacity, but also the differences of potentials, V - V', must have a considerable value, but when the stress in the field reaches a limit depending on the nature of the material, the dielectric gives way and is burst through by a disruptive discharge. By combining several Leyden jars so that all the inner coatings are electrically connected by insulated metal rods, and the outer coatings are connected by placing the jars in a box lined with tinfoil, the capacity of the combination a Leyden battery - is equal to the sum of the capacities of the separate jars.

Charging a condenser consists in establishing a difference of potentials between the boundaries of the corresponding electric field, while the discharge consists in bringing its two surfaces to the same level. This discharge may be done suddenly by connecting the two surfaces by metal rods, (discharger), when a bright loud spark passes between them before they are quite in contact, and the jar is afterwards found to be discharged; or the discharge takes place in a different way or by successive contacts if the surfaces instead of being connected with each other are alternately connected, one at a time, with a third conductor.

The energy of a condenser like that of an electric field is represented by $W. = \frac{1}{2} Q. (V - V')$ and the energy of a combination of charged jars is equal to the sum of the energies of the separate jars.

I have formerly spoken of the 'dielectric co-efficient' or 'specific inductive capacity' which is the property of the material occupying an electric field, of given shape and size, which determines the charge required to produce a given difference of potentials between the boundaries of the field. This co-efficient is taken as equal to one for air and varies correspondingly for other substances. After the discharge of a Leyden jar it is found that a slight difference of potentials of the same sign as that previously existing, remains, and this is spoken of as the residual charge.

The discharge of the energy of an electric field may take place in one of two ways. Either the discharge is conductive, in which case its work is chiefly expended in the conductors, or disruptive, when the greater part of the available energy is absorbed in a spark and in either case, owing to resistance of the conductors, a certain amount of energy is always transformed into heat. The length of the spark in air, under the ordinary pressure, or what is known as the striking distance, depends on the difference of potentials of the two electrodes.

Electrical machines are contrivances which serve as the source of electric energy, that is to say, from which a certain amount of positive electricity can be transferred in one direction and an equal amount of negative electricity in the opposite. These machines are essentially of two kinds:- (1), where friction plays the essential part in the electrical production, and, (2), where the electric production is due to induction.

Towards the close of the Eighteenth Century, two men, Galvani and Volta, proceeding from the discovery that wires proceeding from a plate of copper and a plate of zinc placed side by side without touching in a vessal of water show a difference of potential amounting to about one volt, were instrumental in introducing a workable electric machine - Voltaic Pile or Galvanic Battery - which has formed a type for machines up till the present day. By arranging several cells in series, Volta found that by attaching wires to the two endmost opposite elements, the difference of potential was equal to the difference found in the case of a single cell multiplied by the number of cells.

The mere contact of heterogeneous metals was, according to Volta, sufficient to afford a constant stream of electricity, the production of it being due to a transformation of thermal energy, but this theory was not accepted by those who came after him and the following theory was substituted.

Regarding oxygen as consisting of two atoms,

$\overset{+}{O}$ and $\overset{-}{O}$, it is supposed that on the exposure of zinc the negative atom unites with it, and so lowers its potential below that of the air, until the resulting electric force counterbalances the chemical force tending to cause further combination, this occurring when the potential of the zinc is about 1.8 volt below that of air, and in the case of copper, about .8 volt below that of the gas.

On connecting the zinc and copper, equalisation of potentials takes place, and thus in the case of both metals, the potential is altered, so that it no longer causes equilibrium between the chemical and electrical forces, and thus further change must take place until the original difference between each metal and the air is regained. But as the two metals must remain at equal potentials, it is thus evident that there must now exist a difference of potential between portions of the gas in contact with the zinc and copper respectively, and thus there is an electric field established in the gas, the difference of potentials between the boundaries being one volt.

The energy is thus derived from the energy of chemical combination between the metal and the surrounding gas.

From one end of such a battery there is a distribution of positive electricity, i.e., the positive pole, while from the other comes negative electricity, i.e., the negative, and it is the tendency of these separated electricities to unite that produces a current and, as it has been broadly stated, "the intensity of the electrical separation becomes the measure of what we may term the electromotive force".

To understand more fully the signification of 'electromotive force' I will take the case of a plate of copper and a plate of zinc dipping into water without touching.

Here, as has just been seen, the difference of potential between the two metals is equal to about one volt. Join a copper wire to the zinc and another to the copper plate and now the difference of potential between the terminals - the plates - is less, and thus is less than the electromotive force of the cell, which necessarily is the algebraic sum of the differences of potential occurring at all the surfaces of contact of different materials intervening between the terminals of the cell.

By the action of a galvanic battery, an electric field is established, the boundaries of which are the surfaces of the conductors attached to its terminals, and if a continuous wire connects the terminals of the battery, a continuous electric current is obtained.

With the passage of this current through a galvanic cell, of necessity chemical action, as I have shewn, takes place among the materials, so that diminution of electromotive force occurs and consequently a weakening of the action of the cell, which is described as due to polarisation of the cell.

In order to avoid this, batteries have been devised and are now in use - Constant Batteries - by means of which the electromotive force is kept constant for a very long time, cf. Daniell's, Grove's, Bunsen's, bichromate, Leclanché batteries.

Connect the terminals of a battery by a continuous wire or any conducting medium and one obtains an electric current. How? Because as the connecting wire tends to bring the two terminals to the same potential, so, at the same time, does the battery tend to keep up a difference of potential between them equal to its own electromotive force, and thus there is a continuous movement of the positive and negative electricities, the direction of the current being held to be that of the positive electricity from the positive terminal through the connecting wire to the negative one. Further it has been concluded that this current is of the nature of a continuous circulation, every section of the circuit being traversed simultaneously by the same quantity of electricity, the measure of this quantity in a given time forming the strength of the current. This unit of current is called an ampere and corresponds to a coulomb per second. Now, it is evident that in the case of such a current the difference of potential must vary at different points of the circuit and that the potential decreases in the direction of the current.

On examination by means of the electrometer it is found that when a current is flowing the difference of potentials between the terminals is less than when no current is passing, and that the difference is proportional to the strength of the current and to another factor called the resistance, and this resistance of the conductor may then be shortly defined as the drop of potential corresponding to a current of unit strength traversing the conductor. The resistance varies with the nature of the conductor, and this was first clearly recognised by Ohm and the unit of resistance is consequently called an ohm after him.

This unit is such "that an electromotive force of one volt applied to a homogeneous metallic conductor, having this resistance, will maintain in it a current of one ampere".

Further, he laid down this - Ohm's Law - that:-

$$\text{ohm} = \frac{\text{volt}}{\text{ampere}}; \quad \text{ampere} = \frac{\text{volt}}{\text{ohm}}; \quad \text{volt} = \text{ohm} \times \text{ampere},$$

and by means of this law one is able to calculate the strength of the current that a given battery will produce through any conductor of known resistance which may be connected with its terminals.

So far we have been considering the propagation of electricity by means of linear conductors, but it is necessary also to take into account the cases where the conductors are of two and three dimensions. If one pole of a battery be connected with a non-linear conductor the current spreads out uniformly over it and the flow takes place along straight lines drawn from the point of entrance to the point of exit. If the conductor be homo-resistant, and the other electrode far away, the lines of flow diverge regularly from the shortest line, being greatest in number close to it, and thus the greatest effect is produced here. When one electrode is very large and the other small - termed monopolar method when applied to man - effects of the current are very much greater at the smaller than at the larger electrode. Where the two electrodes are of equal size the method is termed bipolar.

Again, it is extremely important to study the propagation of a current through a complex heterogeneous conductor. In this case the lines of flow do not follow a simple, direct course, but their trajectory is very complex and according to the law of Kirchoff, when a current divides into several derived currents the intensity of the principle current is equal to the sum of the intensities of the derived currents, the intensity of such a derived current varying inversely as the resistance.

Take for example the case of the human body in which, according to Eckhardt, the specific resistances of the tissues, taking that of muscle as 1, are as follows:-

Muscle	= 1.
Tendon	= 1.8-2.5
Nerve	= 1.6-2.4
Cartilage	= 1.8-2.3
Bone	= 16-22.

Thus in administering a current of 2 milliamperes to a nerve the neighbouring muscles are subject to a current of 4 milliamperes.

By means of an electric battery we have a transformation of chemical energy into electrical energy and "during the passage of the current, chemical action goes on in the battery, such that the products of the action possess less chemical energy than the materials from which they are formed, and the difference is available for the production of electrical energy", and, as "the energy of the circuit does not, on the whole, either increase or decrease during the passage of a current, so the amount of energy given out by it in a given time must be the same as the amount received by it in the same time."

Now the difference of potentials, F., between the terminals of a battery is less than the electromotive force, E., by the product of the resistance of the battery, b., into the strength of the current, or, $F = E - bc$. Hence the fall of potentials which the current undergoes outside the battery is F, and the whole of the energy of the battery which is available for doing external work may be represented by FQ. which is less than the total energy of the circuit.

Suppose the interpolar wire of a battery to be cut and the two ends placed in a liquid containing salts liquified either by solution or by fusion. As the current passes - such a solution is a conductor - decomposition always takes the place of such a nature that there is a separation of the metal from the simple or compound radical with which it was combined.

This action is termed electrolysis and the liquid decomposed is termed electrolyte, while the conductors by which the current enters and leaves the liquid are called respectively the positive and negative electrodes.

The resistances of electrolytic conductors are very high compared with those of simple metallic conductors, but while the resistance of metals is increased by rise of temperature, the resistance of electrolytes is decreased by it.

The constitutents into which a body is decomposed never appear in the mass of the liquid itself, but only at the electrodes, the metal at the negative and the radical at the positive electrode.

The elements of an electrolyte are termed ions and those which appear at the anode are called anions, while those which appear at the kathode are called kations. Every electrolyte must contain more or less water.

Should the electrode be subject to chemical alteration the body so given off will now be the cause of secondary actions in conjunction with the electrode. Thus suppose electrolysis to take place in a solution of common salt; here "the sodium liberated at the negative electrode decomposes water, with the formation of sodic hydrate, $NaOH$, and liberation of hydrogen; at the positive electrode, chlorine is liberated, partly in the form of gas, while another portion decomposes water with formation of hydrochloric acid and liberation of oxygen, and another portion still is converted into hypochlorous acid and other oxygen compounds of chlorine."

In the case of acidulated water, oxygen is liberated at the positive electrode and hydrogen at the negative, and the volume of the latter is twice that of the former.

The quantity of an electrolyte decomposed by a current depends on the nature of the electrolyte and on the quantity of electricity which passes.

It has been before noted that polarisation of a galvanic cell takes place owing to chemical change during the flow of a current, and it has here to be noted that likewise polarisation of the electrodes may take place. Between such polarised electrodes it is found on disconnecting the battery that a current passes through the liquid from the negative to the positive electrode, that is to say, in the opposite direction to the battery current. This current, due to the electromotive force of polarisation, is called a <u>polarisation current</u>.

Making use of the knowledge of this fact, instruments named accumulators have been made by means of which the current worked with is the polarisation current.

Magnetism.

"The name magnet or loadstone is applied to certain specimens of natural oxide of iron (Fe_3O_4), which possess the property of attracting iron filings." The ends or poles of the magnet are the parts which chiefly show this property. "By simple friction, and without itself losing any of its properties, the stone can impart to steel the property of attracting iron." Owing to the action of the earth, one pole always turns north, - positive pole - the north pole - and the other south - the south pole - negative pole and it is found that as in the case of electricity so here - two poles of the same kind repel one another, and two contrary poles attract.

As for electricity so for magnetism it has been found that the same fundamental laws as regards quantity, field, potential, etc., exist. Any piece of iron placed in a magnetic field becomes a magnet and this phenomenon is known as magnetisation by induction and is analogous to the inductive electrification of an insulating body.

I propose now to consider the phenomena known as electro-magnetism or the external actions of an electric current in contra-distinction to the internal actions, that is to say, the effects produced by the current in the conductors traversed by it and which has already been considered. "When a conductor through which a current is passing is brought near and parallel to a magnetic needle, the latter is deflected from its ordinary position and according to the relative positions of the needle and the circuit, the direction of the deflection is different. Suppose an observer swimming in the direction of the current, so that it enters by his feet and emerges by his head; if the observer has his face turned towards the needle, the north pole is always deflected to his left." It is found moreover that the amount of deflection of the magnetic needle varies with the strength of the current and thus we get an apparatus formed for measuring the current termed the Galvanometer.

From experiments by Oersted and Ampere it is proved that an electric current creates a magnetic field, and acts on magnets or on other currents in the same sort of way as magnets themselves. The similarity of action of magnets and currents has led observers to attribute the two orders of phenomena to the same cause, and it is assumed that each magnetic molecule owes its properties to a current of electricity about its axis.

In 1820 it was observed by Arago that magnetisation of iron takes place by an electric current - electro-magnets - and the magnets thus obtained may be made exceedingly powerful, and at the same time possess the property of being essentially temporary and of only existing during the passage of the current.

In 1831 a discovery was made by Faraday. He found that "a current which begins to flow, or increases in strength, or is brought nearer, produces in an adjacent circuit an inverse induced current; a current which ceases, or diminishes in strength or is moved away, produces a direct induced current."

At the same time he discovered that magnets may be used to play the part of currents in these phenomena.

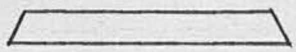
"Both effects are obtained simultaneously and with far greater strength by placing a core of soft iron in the inducing coil. When the current is made, the cylinder of soft iron is magnetised, and the two actions, of the coil and of the magnet, which are evidently in the same direction, are added together. They are also added when the current is broken."

This secondary induced or Faradic current is, therefore, an interrupted current as it occurs only at the moment of opening and closing the primary circuit, the current alternating at each interruption.

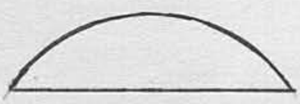
Let us now consider shortly the graphic representations of various forms of electric currents.

In the first place, the current when made may rise abruptly and suddenly from an intensity of zero to its maximum, which it retains a certain time and then, as abruptly, returns once again to zero.

I represent this, thus:-

zero  zero.

taking the abscissa to represent time and the ordinate intensity of current. If, however, the rise and fall occur not brusquely but gradually the intensity of the current may be represented thus:-

zero  zero

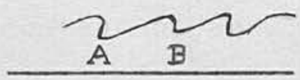
Now, I have spoken formerly of the constant or continued current, i.e., the galvanic current, and the intensity of this current naturally would be represented by a line parallel to the zero line:-

zero zero

the formation and cessation of the current occurring, however, in one of the above forms according to the rapidity with which it is produced.

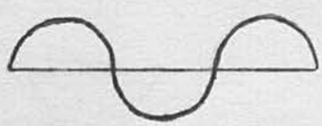
Again, the intensity of a current may vary in a definite continuous manner without ever becoming permanent and such a current is termed oscillatory or periodic where the variations are always identical.

This current may be represented thus:-

zero  zero.

the part between A. and B. being termed a period, and the frequency of the current being measured by the number of periods per second.

Further, a periodic current, each of whose periods is composed of two demi-periods, equal and of opposite sense, is termed an alternating current, that is to say, one half of the period is positive and the other negative, thus:-

zero  zero.

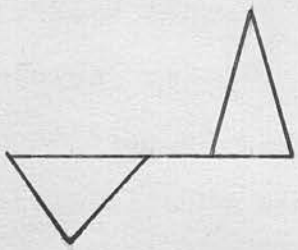
Now, a <u>sinusoidal current</u> is an alternating current whose intensity varies according to the same laws as the movement of a pendulum and it is the simplest form of an alternating current.

This current, therefore, varies regularly, rising from zero to attain its positive maximum and sinking again to zero from which it increases again and to the same maximum in a negative sense before returning once more to zero.

To M. d'Arsonval is due the introduction of this current and the origination of a suitable machine.

As regards the faradic current it has already been mentioned that on making and breaking the primary circuit this induced current is obtained consisting on each occasion of equal quantities of electricity of opposite sense. Now, while both those induced currents are termed momentary it is found that as a matter of fact the current induced at the making of the primary circuit lasts nearly twice as long as that produced at its breaking, and in the interval between the two, no current passes.

Representing this graphically we have:-

zero  zero.

II. ELECTRO-PHYSIOLOGY.

The changes brought about by the application of electricity to the human body may be divided into two groups:-

(a) The physico-chemical effects.

(b) The Physiological effects.

A. 70% of the human body consists of water and thus it may be regarded as a mass of liquid containing various substances, specially salts in solution. It is, in other words, an electrolyte, the passage through which of an electric stream causes, from the moment of entrance of the current at the positive electrode through the resistant skin and subjacent structures, till its exit at the negative electrode, a condition of electrolysis. The effects of this electrolysis on each separate molecule of a substance are to split it up into two components or ions, one positive and one negative, the former, anion, being driven to, and appearing at the positive electrode, the latter, kation, at the negative electrode.

Hydrogen and metals are kations, while the anions are the acid radicals including the halogens and the hydroxyl group.

A considerable amount of the resistance of the human body to the flow of electricity is due to the skin, the chief resistance of which is located in the epidermis. When dry it may be considered as an insulator, but its resistance diminishes in proportion to the degree of its moisture.

Now, at the electrodes a double action takes place, kations pass from the fluid at the positive electrode into the body, and anions pass out from the body, while at the negative electrode the reverse takes place, kations coming from, and anions passing to the body.

This has been proved experimentally to be a fact; strychnine placed at the positive electrode quickly killing an animal and when placed at the negative being without effect, while cyanide of potassium acts conversely.

These effects have of late years been studied specially by Frankenhauser* and more particularly through the researches of Schazkij[x] it has been proved that not only at the two poles but also throughout the entire interpolar district do these changes occur.

---

*Zeitschr. f. Elektrotherapie u. arztl. Elektrotechnik, 1900 Heft 1.

[x]Do. Do. 1900 Heft 1. and 2.

This last is an extremely important fact and knowing it we can understand how by such means the results of disease difficult of absorption may be driven to, and given off from the surface or rendered more readily absorbable and so eliminated by natural processes.

The tissues, be they homogeneous or heterogeneous, are the seat of a transport of ions in both directions. If the tissue be homogeneous its chemical composition remains unaltered by the passage of the current as each individual molecule gives up to the next that which it received from the previous one. But where two tissues of different nature adjoin their chemical composition is modified as the fluid of each receives foreign constitutents from the fluid of the other.

It is difficult, however, to judge of the exact amount of importance to be attached to this action in electropeutics, and there can be no doubt that many patients can be as satisfactorily treated by the faradic stream - which exerts exceedingly slight electrolytic action - as by the galvanic.

Moreover, in order to have this action strongly manifested, it is necessary to deal with very powerful currents, while in many cases, such as neuritis and arthritis, etc., a weak stream acts better than a strong.

Along with Electrolysis there occurs another phenomenon known as Kataphoresis, by which is understood that a number of molecules, unbroken into ions, are, by the mechanical force of the electric stream, driven from the Anode to the Kathode - but little is known with certainty of this phenomenon. Naturally, both electrolysis and kataphoresis are most marked when the constant current is the one employed and very much less so in cases where the interrupted stream and current in alternating directions, such as the faradic and sinusoidal streams, are used.

B. The essential action of the electric current on the body is that of nerve stimulation, so that by its action all those processes governed by nervous energy are affected.

Further than this, however, it is found that certain forms of electricity have direct action on the protoplasm of the cell, thereby increasing metabolism, this being one of the reputed characteristics of the sinusoidal current as compared with the galvanic or faradic; While the high frequency current and galvanic stream are markedly baktericidal.

The degree of nerve-stimulation varies naturally according to the intensity of the stream, but, in addition to this, another factor has to be taken into account, namely, the rapidity of making and breaking the stream.

During the flow of a stream no excitation of a motor nerve is produced, but only on making and breaking the current, the more rapidly this is done the stronger being the excitation. Effects, however, are produced on the vaso-motor and sensory nerves. Through action on the cutaneous vaso-motor nerves redness is produced at the two poles and with a strong current vesicles develop, the effects differing at the two poles and the increased temperature being always greater at the positive than at the negative pole.

By stimulation of the sensory nerves a burning prickly sensation is experienced, especially at the negative pole. These sensory effects are probably partly due to the electrolytic action, but are certainly also partly produced by direct excitation of the sensory fibres. As the sensory nerves, so are the nerves of special sense in like manner affected when the application is in their neighbourhood, and also increased salivation is produced.

If the current be applied to the body by means of metallic electrodes or needles the effects of electrolysis are exceedingly marked and destruction of tissue occurs.

At the same time, by very slowly completing the circuit, it is possible to act with a strong current on a motor nerve without exciting it, whereas a rapid closure would produce strong contraction, as with the faradic current.

The sinusoidal current, which, in common with the faradic, consists of alternating phases, differs from it, however, in the gentleness of the make and break curve and, therefore, has a much less exciting effect.

When using strong currents the above statements must be modified to this extent, that during the flow of the current a very slight excitation of motor nerves does take place, which is so weak as to be unnoticed in the milder streams.

According to measurements made by Blaserna of the respective times occupied in the making and breaking of the circuit, the former occupies nearly twice as long a time as the latter and, therefore, is less abrupt.

Various observers, working at the effects of the galvanic current during these periods of make and break on the human body, have recorded results which do not altogether harmonise in every detail. The effects are produced on the muscles and motor nerves.

Professor Erb has tabulated the following results of his numerous observations by the monopolar method:-

1st. Feeble Current.

A contraction is produced at the negative pole on making the circuit.

2nd. Stronger Current.

A stronger contraction is produced at the negative pole on making the circuit, and, moreover, a contraction occurs at the positive pole both on making and breaking the circuit.

3rd. Very strong current.

Tetanus occurs at the negative pole on making the circuit, muscular contractions occur at the positive pole on making and breaking, and a very weak contraction occurs at the negative pole on breaking the circuit.

So much for the qualitative effects.

As regards the quantitative results, according to the same authority, the relations of intensity between the contractions are the following:- taking 4. to represent the intensity of the contraction produced at the negative pole on making the circuit.

Kathodal closing contraction		= 4.
Anodal closing	"	= 2.
Anodal opening	"	= 2.
Kathodal opening	"	= 1.

or, where K = kathodal or negative; A = anodal or positive; C = closing or making; O = opening or breaking, and c = contraction,

KCc = 4.

ACc = 2.

AOc = 2.

KOc = 1.

When the effect on the muscles direct is considered apart from action on the nerves, the results are found to be more simple.

The closing contraction at either pole is stronger than the opening, while it is always the case that the closing contraction is strongest at the negative pole.

Turning now to the faradic current, let me first of all draw attention to some characteristics of muscular contraction.

Indirect stimulation of a muscle, that is, stimulation through the motor nerve of that muscle, always produces much stronger contraction than direct stimulation, as, in the former case, all the fibres inervated are stimulated, while in the latter, the action is much more localised.

Tetanus consists in the superposition of muscular contractions one on another, each successive one occurring before relaxation from the former has occurred, and, as a result, is evidenced by a sort of convulsive trembling in the body. The production of tetanus, therefore, requires a certain number of stimulations per second, as, for instance, by a faradic current, the fusion of contractions constituting the tetanus being due to muscular elasticity.

Should this tetanic condition of the muscle be prolonged, however, the muscle eventually relaxes even though the stimulation continues, and this is owing to fatigue of the muscle.

With the faradic current each make and break of the primary circuit produces a muscular contraction, tetanus being caused when these stimulations occur from 20 to 30 times per second and over.

As the number of stimulations increase the tetanic result becomes more marked up to a certain limit above which it again diminishes and finally disappears completely. This limit has been fixed by d'Arsonval at between 2,500 and 5,000 stimulations per second.

I have previously discussed the form of the faradic current and noted that the current induced on making the primary circuit is less abrupt and longer continued than that produced at the breaking and it is found that physiologically the former current is practically a negligible quantity owing to the slightness of its effects on the muscle, while the latter current it is which produces the characteristic motor and sensory effects of the faradic current.

And owing to this condition of affairs it is found that it is possible to recognise a definite anode and kathode of the induced circuit.

The fact noted above, namely, that the current induced on breaking the primary circuit is the important one, is readily demonstrated by the sensation received on applying the two electrodes connected with the secondary current to the body. It is found that the sensation is most acute at the electrode corresponding to the kathode, i.e., the electrode at which the current enters the body on breaking the primary circuit, while on reversing the current the other electrode becomes the stronger.

D'Arsonval has spoken of the "caracteristique d'excitation", by which he means the curve obtained by taking the time as the abscissa and the variations of potential as ordinates, and it is the form of this curve which governs the physiological motor effects which follow stimulation of muscles or nerves.

In the faradic current of rupture this curve rises very abruptly and for this reason these currents cause contraction and tetanisation of muscles. By lengthening the time relatively to the increase of potential d'Arsonval succeeds in completely modifying the physiological effects of the current motor and sensory.

Faradisation is without doubt the agent by preference for acting on muscular contractility by means of which artificial gymnastics can be practised.

Take for example the experiments of Debédat*. In these he applied faradic electricity to certain muscles of one leg of a rabbit in the first case having 20 séances each of 4 minutes duration. Thirty faradic shocks were given per minute, or a shock every alternate second and the results obtained were as follows:-

Weight of rabbit at commencement	.	892 grammes.
" " " after 20 séances	.	1150 "

	Non-faradised.	Faradised.
Weight of Biceps . .	4.6 gr.	6 gr.
" " Semi-tendinosus	1.4 gr.	2.1 gr.
" " Semi-membranosus	3.5 gr.	5 gr.

Not only so but histological examination proved the increase to be due to true muscular hypertrophy.

---

*Archives d'elect. méd. 1894, p.69.

If, however, the current be too strong or too long applied the results obtained prove very different. For instance:-

Weight of rabbit at commencement:- 682 grammes.

" " " after 20 days:- 720 "

	Non-faradised.	Faradised.
Weight of Biceps . .	3.2 gr.	3.05 gr.
" " Semi-tendinosus	1.2 gr.	1.2 gr.
" " Semi-membranosus	2.4 gr.	2.25 gr.

the decrease being due to atrophy of the muscular substance.

In what manner now is it that the electric current acts as a therapeutic agent?

Probably the effect through vasomotor nerves on the circulation is not the most important action. General blood pressure is a variable quantity subject to numerous influences, and it would appear that compared with, say gymnastic exercises or cold douches, the electric current has little influence on it. One is forced therefore to seek as a cause of beneficial therapeutic applications in the influence of the current directly on the motor and sensory nerves.

Now, in order to improve the condition of an affected motor or sensory nerve, it is necessary that after ceasing the application of the current this nerve is left in a better condition than formerly and will re-act more readily both to electric stimulation and to the natural stimulation from the central nervous system.

Thus the therapeutic action of electric nerve stimulation and probably the most important action in electrotherapy consists chiefly in a variation of excitability, sometimes an increase, at others a diminution, according to the pathological condition, - for example, an increase where the condition is paresis of a motor nerve or diminution as in neuralgia.

Is it possible to bring forward proofs to show that this variation of nervous excitability is really produced by the electric current?

Let us consider separately the effects produced on the nerve excitability,

(1) At the time of the electric application and,

(2) Those which remain afterwards.

1. As regards the first, many observers have studied the changes produced by the constant current.

It has been proved by experiment that when a nerve forms part of a circuit of a flow of galvanic electricity its excitability is increased at the kathode, (katelectronus), and diminished at the anode, (anelectrotonus), while on suddenly breaking the current these changes of excitability cease, though when the current is very gradually stopped they remain a short time.

If, however, the current be very strong the quietening effect at the anode may be overcome by the exciting action from the kathode so as actually to produce nerve stimulation and thus for instance, in treating neuralgia with the anode when too strong a current is used more harm than benefit results. A ready example of the above action is found in cases where abnormal noises in the ear are heard. By applying the anode to the ear in such a case the noises completely vanish owing to the soothing action on the auditory nerve, whereas the kathode serves to increase the loudness of the sounds.

These polar effects are found in motor and sensory nerves alike.

As regards the faradic current it seems to be the case that weak currents produce no change in excitability, moderately strong currents produce increased excitability, and very strong tetanising currents produce for several minutes a diminution of excitability, this being true for both motor and sensory nerves.

Similar to the faradic current is the action of the sinusoidal current with this modification that owing to its very gradual rise and fall it has a specially quietening effect on the sensory nerves.

Another consideration occurs here. When, through stimulation from the brain, increased excitability cf. pain is produced in some deep-seated part of the body it is found that electric stimulation and more particularly that which <u>increases</u> nervous excitability, when applied to the skin over this part serves to diminish the exciting action from the brain and, consequently, the pain.

We see, therefore, that a diminution of nervous excitability may be brought about by:-

<u>a</u>. Direct application of the galvanic anode.

<u>b</u>. Direct application of a long-continued very strong faradic current.

<u>c</u>. Indirect application of a short and strong, or weak and lasting faradic current.

While increased excitability is produced by:-

<u>a</u>. The galvanic kathode.

<u>b</u>. Moderately strong, short faradic stimulation.

So far it is plain that by using different agents we can obtain diminution or increase of nervous excitability, and not only are these changes apparent when dealing with an electric current, but it has been fully proved that they are true also as regards the natural methods of stimulation, that is to say, a nerve whose excitability has been increased by electricity responds more readily, not only to electricity, but to will impulse and vice versa.

2. Are these effects absolutely transitory or of a lasting nature?

It has been well established that by oft-repeated stimulation the excitability is increased and therefore, the power of conduction and of functioning also.

The effects themselves are of a merely transitory nature, and it is only by repeated application of the stimulating or soothing agent that a lasting result can be obtained.

By consideration we can understand how it is that in a case, say of hemiplegia, electric stimulation of the arm and leg is of great use even though the lesion be in the brain.

The electric stimulation produces increased excitability of the peripheral nerves, and, consequently, slighter brain efforts produce greater effects. The same also holds good when the soothing applications are indicated, as, for example, in neuralgia, or where we desire to diminish pathologically increased function of an organ.

Now, as to the changes which take place in the nerve substance, Weigert has shewn that consumption of substance occurs when nerve energy is expended.

If this consumption be not too great and not too quickly renewed it is succeeded by compensation which exceeds the previous loss.

Thus, if the expenditure of energy be too great, insufficient compensation occurs and the nerve suffers a lasting injury, while through moderate use or electric stimulation increased power is obtained.

III. PHYSIOLOGY AND THERAPEUTICS OF ELECTRIC BATH.

Where electricity is to be used in the form of an electric bath the essential is that the water of the bath shall form part of the circuit, and that thus, the electric current flows through it from the one electrode to the other.

A patient placed in such a bath is, therefore, subject to general equable electrisation throughout all the body in contact with the water.

Various forms of bath have, at different times, been proposed and devised, of many of which it is unnecessary to treat, but it is important to distinguish between the two following methods.

These are known as the <u>monopolar</u> and the <u>dipolar</u>.

<u>Monopolar</u>

In this method one pole is connected with the tub in which the patient is placed, if this is of metal, or passed into the water, if the vessel is of some non-conducting substance - as of wood. The current entering the water is conducted to the entire surface of the body that is in contact with the water and passes out by means of an iron bar covered with wet chamois skin, which is grasped in the hands.

If the tub be of metal some arrangement must be used, - such as a perforated wooden lining - to prevent the body of the patient coming in direct contact with the metal, and with the same object the electrode introduced into a wooden tub must likewise be protected.

By means of this arrangement it is evident that all the current passing from all parts of the patient's body in contact with the water is concentrated finally in the arms before passing to the other electrode and thus a current which causes severe contraction of all the muscles of the hands and arms is so spread over the rest of the body as to be barely preceptible. If the kathode be connected with the water the bath is termed kathodal; if the anode - anodal monopolar bath.

Dipolar.

In this method of administration the body of the patient does not come in contact with either of the electrodes, but these are immersed in the water, one at each end of the tub, which must be of some non-conducting material. In this way the whole of the current does not pass through the body, the amount which does pass varying with the temperature and amount of the water.

Unlike the monopolar method there is no concentration of current at one pole.

The amount of current passing through the water is increased by raising its temperature or by adding to it such substances as salt, or a little acid, and, consequently, the amount passing through the body diminishes accordingly.

By means of such baths treatment can be continued by the various forms of electric current.

The temperature at which the bath is usually given varies from 90° to 100° the patient remaining in it 10-30 minutes.

Now, while it is evident that by the monopolar method the exact amount of current which passes through the patient's body is accurately known, in the case of the dipolar method this is not the case.

A variety of conclusions are arrived at by various observers, the net result of which appears to be that the amount passing through the body is from $\frac{1}{8}$ to $\frac{1}{4}$ the amount introduced into the water.

The therapeutic effects of the electric bath noted by observers serve to show that the stimulating, sedative and tonic effects of electricity are obtained more or less by all forms, while the baths can be borne by temperaments that will not bear ordinary electricity. One effect of the electric bath appears to be to give tone to the cutaneous vessels, so that there is less liability to take cold than after a simple warm bath.

"The conclusions of the various observers are unanimous in showing that the pulse rate is considerably diminished (8 to 20 beats per minute) in both the galvanic and faradic baths. (Eulenburg, Lehr, Schleicher, V. Corval. Wunderlich).

Respiration is diminished (3 to 6) in the dipolar, little, (1 to 2), or not at all in the monopolar bath. The temperature is lowered by the latter 0.1° to 0.7°C. Metabolism is promoted considerably by the dipolar; slightly by the monopolar bath (Lehr); and there is increased secretion of urine. Appetite and digestion are improved. The genital functions are stimulated. Circulation and nutrition are benefited: sleep notably restored, and new vigour imparted to the mental and physical faculties. In short, the electric and especially the faradic bath is credited by all those writers with a powerful, invigorating and refreshing action upon the human frame."

In states of debility and impaired nutrition and especially in the various functional neuroses the electric bath and more especially the faradic is of undoubted value.

It is also beneficial in tremulous conditions, and does good in the spasms and rigidity of hemiplegia and spastic paralysis, while it has also been given with advantage in muscular rheumatism and old and chronic forms of articular rheumatism.

IV. THE SINUSOIDAL ALTERNATING CURRENT.

The introduction of the sinusoidal alternating current into the world of practical therapeutics was the work of Professor d'Arsonval.

In the year 1889 he published a paper on the subject in which he first brought forward the important point of what he calls the characteristic of electric stimulation.

In this paper he commences by recognising the mistake made by thinking that one has completely defined an electric stimulation, from the physiological point of view, by knowing the strength and difference of potential of the current employed, as these two factors merely give the amount of energy liberated by the apparatus at the moment of discharge.

This is easily proved by experiments from which it is readily apparent that there is no relation at all between the energy of an electric stimulation and the muscular contraction which results from it.

Take, for example, the case where application is made from a condenser of capacity 1/10, at potential 10. On discharging it violent contraction ensues, whereas, by using a condenser of capacity 10, charged at potential 1, only feeble contraction or none at all occurs on discharge.

Or again, apply suddenly a strong current at full strength and violent contraction results; apply the current slowly, gradually increasing up to the same strength and the effects are much less marked. A third factor, therefore, has to be taken into consideration when defining completely from the physiological point of view the electric stimulation. This factor is time.

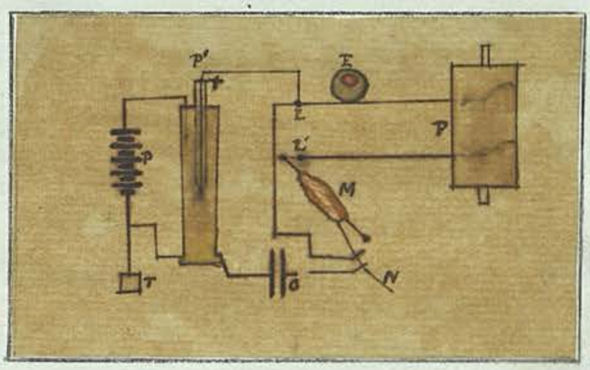
In examining a single electric stimulation, such as that from the induced current on breaking a primary circuit, it is evident that the electric variation leaves a potential of zero to attain a maximum potential and then returns to zero. It can, therefore, be graphically represented by a curve, by portraying the variations of potential on an axis at right angles to another axis on which figure the variations of time.

This curve it is which is called the characteristic of electric stimulation and in it M. d'Arsonval considers the following factors have to be observed:-

1. The maximum variation of potential.
2. The phases of this variation which is to be continued.
3. The duration of the variation.
4. The amount of electricity put in motion.

He says, "If it were possible to inscribe graphically this curve, if it were possible to vary separately each factor of it, if it were possible, finally, to inscribe beneath this characteristic of stimulation the contraction which results from it, then, and then alone, one could distinguish the laws which bind the muscular and nervous re-action to the different qualities of electric stimulation."

Such a contrivance he devised and describes it as follows:-



"Let P. be a constant current battery (Daniell or accumulators) whose circuit is closed through the vertical glass tube filled with a solution of sulphate of copper or mercury. The current enters from above by means of a ring of copper and flows out at the foot of the tube by means of a similar plug of copper. The negative pole of the battery and the foot of the tube are put in metallic communication with the earth and are consequently at zero potential.

The upper part of the tube is, on the contrary, at a positive potential equal, let us say, to 10 volts. Passing down the tube, therefore, the potential gradually diminishes from +10 V. to zero. Suppose that a metallic thread, P', insulated up to its lower extremity, can rise and fall in the tube. Its point, when at the bottom of the tube, has a potential of zero, but on raising the thread its potential increases regularly from zero up to +10 V. Fix this metallic thread to a lever, movable round the point L, the other extremity of the lever working on the smoked cylinder F. It is easy to see that the displacements of the point of the lever L, on the cylinder F, describe the phases and amounts of the variation of potential. In order to have a definite curve to begin with one makes the lever oscillate by the rotation of an excentric E, which one can arrange at will.

In practice, I have always used, as a lever carrying the dipper, either a vibrating rod or a pendulum, which gave me a sinusoidal variation of potential; but it is easy to obtain any form or any rapidity by the action of a spring as I have used in the experiments which I bring forward later. If the thread P' were put simply in relation with a nerve in communication with the earth, this organ would be constantly traversed by a derived current which would rapidly alter its excitability; moreover, one would have no means of graduating the amount of electricity through it.

To avoid this inconvenience I interpose a condenser marked at C. and I place the excited nerve at N. By this means the nerve is only traversed by a current as much as the dipper P' is displaced. For the same displacement of P' the amount of electricity traversing nerve N. is rigorously the same and known beforehand.

Muscle M. adherent to the nerve is attached to the myographic lever L' which traces the curve of the muscular contraction immediately beneath the characteristic of stimulation traced by the lever L."

By means of this instrument there is obtained:-

1. The amount of electricity passing through the nerve at each stimulation.
2. The variation of potential.
3. The phases of this variation.
4. The duration of the variation.

Each and every one of these 4 factors being easily varied separately from the others.

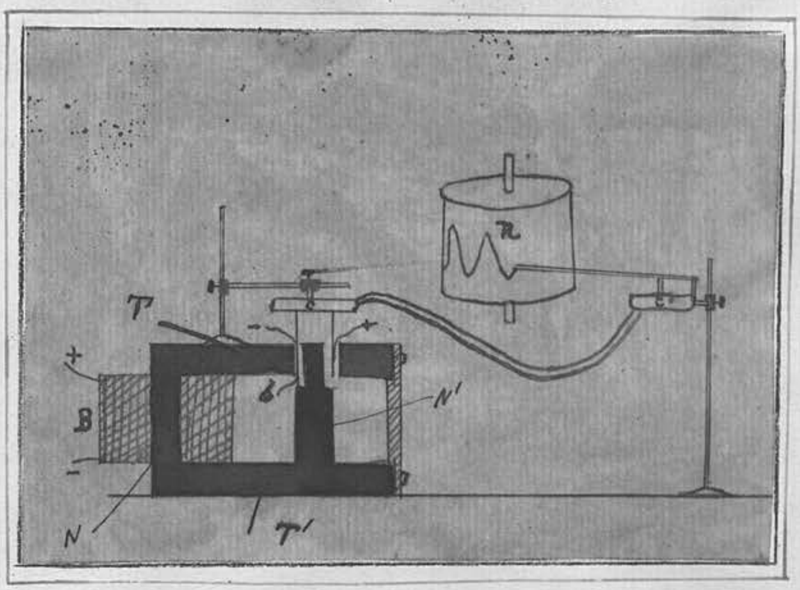
In the conclusion of this paper M. d'Arsonval says:-

1st. "The excitability of the nerve is affected mainly by the rapidity and extent of the variation of potential; the quantity of electricity plays a comparatively secondary role.

2nd. The excitability of the muscle is, on the contrary, affected mainly by the amount and depth of fall of the potential, that is to say, by the physical energy of the stimulation.

In a word, as regards the nerve, the electricity seems simply to play the role of a force of discharge, while the muscle transforms, in part at least, this energy into mechanical work in the manner of an electric motor."

Having proceeded so far his attention was next directed to constructing an apparatus which should be able to trace graphically the form of the waves coming from <u>any</u> electro-therapeutic apparatus and thus to shew experimentally that the variation of the physiological effects of electric stimulation is intimately connected with the variation of the form of the wave of stimulation.



"NN', TT', électro-aimant à champ magnétique annulaire.

B, bobine animant l'électro-aimant.

b, bobine mobile suspendue à la membrane C.

C' tambour à levier enregistreur.

R, cylindre enregistreur recevant la courbe."

This apparatus he describes as follows:-

"This apparatus is composed of a powerful magnet, or better, an electro-magnet, creating an annular magnetic field. In this very powerful magnetic field there is a small coiled thread of copper carefully insulated, which is able to move freely. This coiled thread is extremely light and requires no assistance to roll up. The successive layers of the thread are simply fixed together by gum-lac, and the arrangement is traversed by the electric wave whose form one wishes to determine. By virtue of a well-known action this bobbin will plunge farther or more slightly into the field according to the intensity and the sense of the current running through it.

Its displacement in the field reproduces faithfully the variations of the current. By tracing these displacements, therefore, one is able to obtain a representation of the desired curve. In order to reduce as much as possible the inertia of the contrivance it is necessary to allow only very small displacements of the bobbin in the magnetic field.

On the other hand again it is necessary in order to have a satisfactory curve that the tracing point should have a pretty considerable displacement for even a feeble movement of the bobbin.

This result I have obtained by making use of the method of air transmission of M. Marey. To this end the bobbin is glued to the centre of a slender membrane of Indian rubber covering again a manometric capsule analogous to the tambour and lever of Marey.

This manometric capsule is connected by means of a tube of Indian-rubber with an inscribing tambour similar to that of Marey all the parts of which are small and extremely light so as to avoid enertia. It is the style of this tambour which traces on the smoked paper the desired curve. In order to amplify considerably the displacements of the galvanometric bobbin I have had recourse to the following device. The manometric capsule has a much greater diameter than the capsule forming the inscribing tambour. From this it results that when a very slight displacement of the membrane occurs, a displacement of the membrane of the inscribing tambour is obtained as much greater as the relation between the areas of the surfaces of the membranes.

The lever serves still more to amplify the movement and thus it is easy to arrange that the movements at the end of the tracing style shall be 20 or 50 times as great as those of the bobbin in the magnetic field.

This apparatus is excellently suited to tracing the form of electric waves coming from electromagnetic machines, of the style of Clarke, usually used in electrotherapy. Inspection of the curves so traced allows of immediate recognition of the different physiological effects produced by these machines according to their source and the rapidity applied to the handle."

By the use of this apparatus the various curves from different forms of electric current can be obtained and from the instrument of M. d'Arsonval which is about to be described a pure sinusoidal alternating curve is got.

"It is a sinusoidal current whose chemical action is nil, while reducing to a minimum the action on the sensibility."

Evidently, by their continuous regular variation these currents resemble those from a galvanic battery as far as the sensibility is concerned, and present none of the shocks produced by faradic currents. The adjustment just described suits admirably for currents of a frequency not exceeding 40-50 per second and the frequency of the sinusoidal current when administered by means of a bath never exceeds 40-50 variations per second.

M. d'Arsonval says:- "In a few words I should like to recall how I was first led to employ the sinusoidal current which had, up till then, been unused in electrotherapy.

Wishing to note the physiological effects of the various methods of electrisation I took as test the change brought about in the production of heat and respiratory combustion as being the results at once most easily ascertained and most exactly measured. The changes produced in the organism by electrisation, included under the title of physiological effects of electricity, seemed to me in fact to be wholly lacking in precision.

My preliminary experiments showed me,

1st. that the static electricity bath promotes respiratory combustion.

2nd. that general faradaisation acts in the same manner owing simply to the muscular contractions which it produces and not to any special electric action.

3rd. that the galvanic current, contrary to what one might have expected, is usually without result on this point.

4th. that an alternating sinusoidal current producing neither muscular contraction nor any painful sensation increases very considerably the respiratory exchange of gases.

As explanation of this last case it is impossible to look for the phenomena of electrolysis such as occur with a galvanic current, or to muscular contraction or a special action on the sensibility; the only explanation possible is that of a special electric action due to the sinusoidal form of the current. My experiments in this respect were made not only on animals of various kinds but also on men and they have always given me the same results."

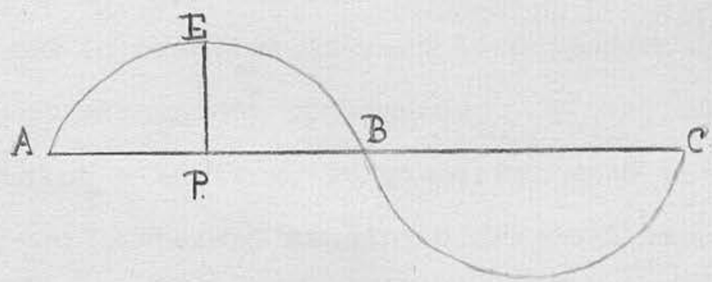
In his efforts to prepare a machine for medical purposes, producing a sinusoidal current, he first of all used an ordinary voltaic battery, and by means of a rotating commutator introduced the elements of the battery gradually into the battery, and then gradually withdrew them. By this means an alternating current was obtained which, however, was very uneven, consisting of a number of steps, and not a true sinusoidal current.

Later he devised am improved instrument consisting essentially of a circular permanent magnet having its two poles at the extremities of the same diameter. This fairly heavy magnet was fastened on an axis perpendicular to its surface which could be set in motion by a pinion or serrated wheel. The magnet turns in front of and very close to an electro-magnet, the position of whose poles corresponds to that of the permanent magnet, and it was in the copper thread encircling the core of soft iron of this electro-magnet that the alternating currents were produced.

As previously stated the electric wave which constitutes the characteristic of electric stimulation is defined by two factors:-

1. The frequency - AB.
2. The maximum ordinate - EP - representing

the maximum variation of potential.



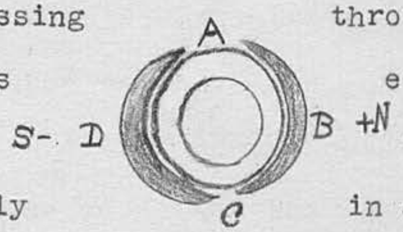
One complete period is characterised by the double curve included between A. and C.

D'Arsonval remarks, "Obviously the current varies regularly, and as the quantities of electricity passing through the tissues are equal and of opposite signs, no phenomenon of electrolysis or of polarisation is possible. The secondary effects due to the passage of the current are thus eliminated and there remains simply the action due to the electricity itself."

It is evident that the frequency - that is, the number of stimulations per second (AB) - is double the number of periods (AC) during the same time.

In the final form of apparatus devised by d'Arsonval he seeks to allow independent variation of the values of the factors AB and EP.

Enclosed by a horse-shoe magnet is a ring of soft iron completely encircled by a series of loops of a continuous coil. This ring with its encircling coil is so constructed as to be capable of revolving and in practice is made to rotate uniformly by means of mechanical appliances. A continuous current, from a battery, is connected with the encircling coil, thereby causing magnetisation of the enclosed soft iron ring. By its position between the branches of the horse-shoe magnet the ring acquires by induction poles at the two ends of a diameter at right angles to the centre of the surface of the two branches of the magnet. Let D. and B. be those two poles and let A. and C. be points taken at the extremities of a diameter at right angles to the former. Following a coil starting from A. and passing through a single revolution, it is evident that from a zero at A. the current increases steadily in a positive sense to its maximum at B., from which it as gradually sinks to return to zero at C. and then increases in a negative sense up to D, to once more sink to zero at A. By tapping the current, therefore, from two opposite coils of the ring we get a sinusoidal current.



The measurement of the sinusoidal current is much more difficult than that of a continuous current it being an alternating current.

To this end special electro-dynamometers have been made, which are capable of measuring sinusoidal currents of 10-120 milliamperes, and thus are suitable in the cases of hydro-electric applications.

In using the apparatus d'Arsonval says, "Both in the case of animals and in man I have constantly observed an increase of the respiratory gaseous exchanges without any muscular contraction whatever. This, therefore, proves indisputably that this kind of current acts powerfully on the nutrition of the tissues. Its application has the great advantage of being painless and of producing no burn or destruction of tissue as takes place with the continued current. This sinusoidal voltaisation has produced in the animals upon which I have so far experimented an energetic contraction of the unstriped fibres without having any effect on the striped fibres, which observations may prove of great value both in physiology and therapeutics."

The current thus championed by M. d'Arsonval has been since that time studied clinically more particularly by Gautier and Larat. D'Arsonval in his experiments measured the intake of oxygen and elimination of carbonic acid by examination of the blood and estimation of the gases in it, but Gautier and Larat found this method impracticable and, consequently, estimated the metabolism in the tissues by analysing the urine and finding the amount of urea excreted.

They examined 200 patients in the following manner.

Before beginning treatment with the sinusoidal current they estimated the total amount of urea excreted in 24 hours, and in almost all cases, after 12-15 applications, they discovered, - especially in those patients who had normally little urea, - a considerable increase of the urea excreted in 24 hours. They at first considered this a verification of d'Arsonval's conclusions, but, on further consideration, doubted this interpretation of the fact for the following reasons.

The patients were not on a fixed diet, and an almost constant result of treatment was improved digestion and increased appetite - specially in chlorotics. The amount of food ingested being increased, naturally, the amount of urea excreted increased.

For general treatment, they used the bath at a temperature of 33°-36°C, and in it they calculated that the patient received 1/5-1/10 of the total current, which itself varied in different cases from 10 volts, 50 milliamperes, to 20 volts, 100 milliamperes. A current of the latter strength they found was hard to bear and it produced general muscular contractions.

Contrary to d'Arsonval, they tried to produce slight muscular contractions, in order to increase the effect of the bath.

The subjective effects of these sinusoidal baths of 15-40 minutes duration each, they found to be:- increased appetite, general feeling of elasticity, and often a regulation of intestinal functions where these were previously out of order.

Sometimes the first baths in impressionable patients produced a little general excitement, and disturbed sleep, more frequent pulse, etc., which phenomena they considered comparable to those often produced by the first sea baths. This excitement always disappeared after the first three or four baths.

Beyond this simple tonic effect, however, they believe that the bath has a powerful influence on impaired nutritive functions and tends strongly in perverted states to cause a return to the normal.

In chlorosis they noted, - immediate improvement of digestive functions even after four or five baths, disappearance of palpitation and murmurs and return of menses - all without any other treatment being used. In cerebral neurasthenia the only symptom they saw improved was insomnia, but in spinal neurasthenia the case was very different. Here feebleness of the legs, pains round the waist and general languor were always relieved.

In cases of obesity sometimes improvement resulted, sometimes not.

In rickets they noted marked results; osseous deformities disappeared and the babies soon looked quite healthy. In muscular dystrophies the results were markedly good and very much better than they would have expected by any other treatment.

In chronic rheumatism, lumbago, torticollis and gout the results were also good.

In eczema they noted successes which they consider due probably to an action on the general nutrition and not to any local action, as eczema on the face and, therefore, not in the bath, healed as readily as those in the water. ?!!

Urticaria also was beneficially affected.

Such is the long list of cases treated by Gautier and Larat and the conclusions they arrive at after careful study.

Professor Bernhardt* in his examinations of

---

*Handbuch der Physikalischen Therapie. Goldscheider und Jacob, 1901.

the effects of the sinusoidal current was led to take a less bright view of the result obtained and states that he has been able to obtain no certain results as regards metabolism, but he finds that it diminishes pain and aids the re-absorption of pelvic exudations when locally applied. In muscular atrophy he found it only of service when there was no reaction of degeneration and only a quantitative diminution of the excitability.

Other observers have studied the effects of the current mainly when applied locally and not when used by means of a bath.

Thus Apostoli and Madame Kaplan-Lapina have noted beneficial results from its local use in gynecological cases, and Kellog states that the most characteristic physiological effects produced by it are:- (1) its painlessness, and, (2) its great penetrating power.

Von Corval and Gaertner while dealing much with electric baths would not seem to have made use of the sinusoidal current. The former notes that a constant result of a faradic bath was slowing of the pulse.

Cohen states, "For all therapeutic stimulation of muscular tissue, when little or no sensory stimulation is desired, the sinusoidal current should be chosen; and then it should be the current _par excellence_ for improvement of muscular nutrition when this is impaired by a failure of proper stimulation. It will, therefore, be found useful for the production of muscular contractions in all forms of nerve degeneration in which faradism is incapable of producing contractions, in many nutritional disorders, and in hyperaesthesias of a functional nature."

V. PERSONAL OBSERVATIONS.

The observations I have been enabled to make on the results of treatment by means of the sinusoidal bath have been carried out in the Departments of the Royal Infirmary and Royal Hospital for Sick Children, under the charge respectively of Dr Dawson Turner and Dr Rainy.

They fall naturally into three groups, namely:-

1st. The effects on a normal individual - myself.
2nd. Effects on patients in the Royal Infirmary.
3rd. Effects on patients in the Royal Hospital for Sick Children.

The control of the patients and their general treatment being in other hands, it was obviously impossible to trust to the method of Gautier and Larat of measuring the excretion of urea, and thus gauging the amount of metabolism in the tissues.

The main result noted by M. d'Arsonval was an increase of the respiratory exchange of gases, which he determined by estimating the amount of gases in the blood.

I, consequently, determined that in addition to noting carefully from time to time the general condition, subjective and objective, of patients under treatment that the most suitable plan of determining the immediate effects of the application would be to carefully examine the temperature, pulse and respiration rate before and after each séance.

In the case of children in the Royal Hospital for Sick Children this method was obviously valueless as frequently, owing to crying, struggling, etc., no satisfactory examination could be made and consequently, merely careful general examination of the child's condition from time to time was made.

1. Effects on a Normal Individual - Myself.

It seemed to me that it would be of some value, while noting the effects of treatment upon sick persons, to be able, at the same time, to examine the effects produced upon a sound individual and to compare the results.

With this end in view, and also with the object of personally experiencing the administration of the current, I resolved to undergo a course of baths.

I, consequently, took a course of baths at the Royal Infirmary similar to those administered to patients there and noted the effects.

In the electric bath department of the Royal Infirmary, Edinburgh, the current is obtained from the main and is of a strength of 250 volts. This main current is tapped and a current of a maximum strength of 50 volts .5 ampere is conducted to an electro-magnetic apparatus, after the style of that advocated by d'Arsonval whence a sinusoidal alternating current is obtained which is conducted to the baths. It was carefully seen that the frequency of variation of the current was always the same. In connection with the current to the bath there was interposed a resistance shunt for regulating further the strength and amount of the current, by means of which the voltage could be regulated from 1 to 50. The milliamperage was not obtainable but great care was taken to see that in every case the conditions were the same, the only varying factor being the temperature of the water.

The current was introduced into the insulating bath by means of large metal electrodes placed at the top and at the foot of the bath, and they were guarded by open basket-work screens.

Prior to entering the bath and after undressing, 15 minutes absolute rest on a couch was enjoined, at the conclusion of which time an examination was made of the temperature, respiration and pulse. Several takings of each were recorded in order to make quite sure of the exact result.

The patient then entered the bath and the temperature of the water was noted before turning on the current. The head and shoulders rested on the upper guarded electrode and the feet were firmly pressed against the lower, the whole of the body, except the head and neck, being submerged.

The duration of the bath was always 15 minutes. At the end of this time the temperature of the water was again noted and the current gradually cut off. Then, before moving from the bath, the patient's temperature, pulse-rate and respiration-rate were again carefully tested.

The baths were administered twice weekly at mid-day.

I, myself, took a course of 7 sinusoidal baths and in addition 2 plain warm baths under the same conditions in order to discriminate if possible between any results obtained by the sinusoidal current from those due to the 15 minutes immersion in hot water.

On each occasion, in order to bring out the effects as markedly as possible, the current through the bath was made as strong as could be reasonably borne.

Subjoined, I note the immediate results obtained

Sinusoidal Baths of 15 Minutes Duration

No. of Bath.	Temperature of Water.	Strength of Current	Temperature. Before	After	Pulse Before	After	Respirations. Before	After
1.	100°-98°	rising to 10 v.	97.6	99	84	95	12	13
2.	96°-94°	10 v.	98.	98.8	90	86	12	12
3.	98°-95°	10 v.	98.2	98.8	90	88	11	11
4.	93°-91°	15 v.	98.3	98.2	90	75	12	11
5.	92°-90°	12 v.	98.6	98.4	85	80	11	10
6.	93°-91°	15 v.	98.2	97.8	86	78	12	10
7.	99°-97°	10 v.	97.4	97.9	76	73	11	9

Plain Baths of 15 Minutes Duration.

No. of Bath	Temperature of Water.	Strength of Current.	Temperature. Before	After	Pulse Before	After	Respirations. Before	After
1.	99°-96°		97.8	98.2	76	76	10	10
2.	93°-91°		98.6	98.2	80	78	12	12

Looking first to the plain hot water baths it would appear that such baths, when taken by a healthy person, at a temperature of between 100° and 90° have practically no effect on the respiration or pulse-rate. On the other hand, there seems to be some ground for supposing that they do exert some degree of influence on the body temperature - as taken in the mouth. It would appear that the warmer baths tend to effect a certain amount of rise of the temperature, while the cooler ones tend to have an opposite effect.

In considering the effects of electric baths I shall, therefore, take it that the effects, as regards immersion in warm water for 15 minutes, on the temperature, pulse and respiration rates, is simply, in the case of baths from 95° to 100° to cause a slight rise in an average normal temperature and the effects of baths from 90° to 95° to cause a slight fall.

Looking now to the results of the electric baths.

Taking first the temperature it is seen that on 4 occasions there was a certain amount of rise and on 3 occasions a slight fall. Every case in which there was any rise of temperature occurred after a bath of a temperature of 95° and upwards, while the cases in which the temperature was somewhat lowered were those where the water was below 95°.

Further, the two occasions upon which the strongest current was passed through the bath, namely, baths 4 and 6, produced alterations of temperature of but .1° and .4° respectively, while on every other occasion but one (bath 5, where a current of intermediate strength was used) the variations were greater in amount.

All these facts, therefore, would go to show that the temperature is no way affected by the electric current or, at all events, only to an insignificant degree when compared with the effect exercised by the warmth of the water.

A glance at the pulse records shows that on 6 out of the 7 occasions there was slowing of the pulse during the bath and on only 1 occasion, namely, the first, was its rate quickened. This also was the sole occasion on which the respiration rate was quickened and I am inclined, so far as the present scrutiny of the figures goes, to leave the first bath out of the question, though later I shall consider it in comparison with other statistics.

My object at present being to record the definite physiological effects due to the flow of the electric current, I wish, so far as possible, to exclude all other factors bearing on the results.

Bath number 1. being the first of the series, of a nature of which I had no experience, of a considerable temperature and lasting for a somewhat prolonged period, accompanied by not altogether pleasing and quite novel sensations, there was naturally a certain amount of mental excitement associated with the taking of it, which would naturally, to a certain extent, be manifest in the results obtained, and, therefore, for my present purpose somewhat disturb the records. The later baths being unconnected with this disturbing element of novelty and consequent excitation give, I consider, fairer absolute results. For instance, in the case of the last bath, of equal strength of current with the first and only 1° lower in temperature, the pulse-rate fell, even from 76 per minute and the respiration-rate was also diminished, whereas, in bath number 1. the pulse-rate rose from 84 to 95 and the respirations from 12 to 13. Taking then, at present, the latter 6 baths only, we find that on every occasion the pulse-rate was lowered by the bath. Not only so, but, apparently, the amount of diminution depends on the strength of current used as in cases 4 and 6, where 15 volts were employed, the greatest decrease was evident, namely, 15 beats per minute in the case of bath 4, and 8 beats in the case of bath 6. In the case of the other 4 baths the greatest diminution noted was 5 beats in bath 5 the only other bath in which a current of more than 10 volts was used.

We may take it then that the effect of the current on the pulse-rate is a tendency to cause a diminution of the beats per minute and that this effect is more marked the stronger the current is.

?

As regards the rate of respiration on 4 occasions this was also diminished, while on 2 it remained stationary, and there would appear to be no very marked relation between the strength of current and amount of diminution. On the whole, therefore, I conclude that as the result of giving a sinusoidal bath one would expect to find a diminution of the pulse-rate to a greater or less degree according to the strength of current used, a tendency to diminution of the respiration-rate and that the temperature would be affected according to the heat of the water - while these results might be quite obscured by external mental impressions on the patient.

As regards the subjective effects of the baths the following notes were recorded. After entering the first bath the current was gradually increased up to 5 volts, when, owing to cramping in the muscles of the leg, it was kept stationary for a time. Owing to the alternating character of the current no difference was felt on altering the poles and the effects were constantly strongest in the legs. After a few minutes, the voltage was increased to 10 v. at which it was maintained. With this strength of current there was a decided tendency to cramping in the muscles of the leg and there were constant tremors in those muscles. This somewhat painful, cramping sensation was strongest in the ankles and gradually grew less intense on passing up the legs. It extended as high up as the loins but no higher and unless movements were made in the water nothing was felt in the upper part of the body. There was no metallic taste in the mouth. After leaving the bath nothing particular was noted.

On 4 occasions a slight transitory headache was noted on leaving the bath and on several occasions a strong metallic taste in the mouth. As a rule, the muscular contractions and pain were largely experienced about the ankles, but, with the stronger currents, the action was also strongly felt in the groins and across the lower part of the abdomen, while on one occasion (the 5th bath) the current was felt much more generally distributed through the body, being felt particularly in the epigastric region and over the region of the heart.

2. Adult Patients treated in Royal Infirmary.

In this group 108 baths were administered, of which the immediate results of 59 are noted below and the number of patients under treatment was 13.

Of these 13 patients,

3	suffered	from	neurasthenia.
2	"	"	sciatica.
1	"	"	hysterical paraplegia.
1	"	"	rheumatoid arthritis.
1	"	"	pseudo hypertrophic paralysis.
1	"	"	neuromata.
1	"	"	chlorosis.
1	"	"	muscular rheumatism.
1	"	"	lumbar pain.
1	"	"	chronic hypertrophic pulmonary osteo-arthropathy.

The baths were administered as formerly described and were given twice weekly.

Subjoined I give the results noted in the case of each administration of the bath.

Sinusoidal Baths of 15 Minutes Duration.

No. of Bath	Temperature of Water.	Strength of Current	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1.	98°-96°	rising to 10 v.	98.9	99.2	78	80	48	40
2.	98°-96°	7 v.	98.6	99.8	96	88	24	24
3.	98°-96°	15 v.	97.6	98	92	100	25	25
4.	95°-92°	17 v.	98.5	98.8	92	100	18	20
5.	100°-98°	18 v.	99.8	100	88	99	24	26
6.	94°-91°	15 v.	98.4	97.8	112	104	24	22
7.	94°-92°	15 v.	98.2	98.2	88	92	32	36
8.	95°-93°	15 v.	99	98.6	100	100	24	26
9.	90°-89°	15 v.	97.3	97.2	62	60	18	20
10.	92°-90°	20 v.	98	98.2	70	72	16	18
11.	95°-92°	17 v.	98.8	99.1	74	90	28	26
12.	99°-96°	20 v.	98.6	98.4	100	108	20	21
13.	96°-94°	20 v.	98.1	97.8	65	75	18	18
14.	97°-95°	15 v.	99.1	98.2	104	84	28	23
15.	94°-92°	15 v.	98.7	98.2	110	114	16	20
16.	94°-92°	21 v.	97.5	97	54	62	20	22
17.	95°-94°	14 v.	98.9	98	68	80	28	28
18	95°-93°	15 v.	99	97.8	82	70	24	24
19.	94°-93°	14 v.	98.2	98.2	68	80	28	28
20.	97°-95°	20 v.	98	97.6	68	82	18	18
21.	94°-92°	13 v.	98.8	98.2	104	120	14	18

No. of Bath	Temperature of Water.	Strength of Current.	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations Before	Respirations After
22.	97°-95°	rising to 15 v.	98.4	97.9	68	78	20	20
23.	99°-97°	15 v.	99	99.4	72	105	22	28
24.	97°-96°	20 v.	99.3	99.5	94	108	22	29
25.	93°-91°	10 v.	98.2	98.2	70	84	27	32
26.	99°-97°	18 v.	99.2	99.4	84	105	22	24
27.	97°-96°	12 v.	98.2	98.2	68	94	30	32
28.	99°-97°	20 v.	98.8	99	79	105	18	26
29.	97°-95°	15 v.	96.8	96.6	73	88	23	28
30.	96°-94°	11 v.	98.1	98	65	90	27	36
31.	95°-92°	15 v.	98.5	97.9	80	77	24	34
32.	94°-91°	11 v.	99.2	98.8	94	89	17	18
33.	96°-94°	17 v.	98.1	97.8	64	90	30	32
34.	96°-93°	11 v.	98.8	98.1	75	75	18	18
35.	96°-93°	13 v.	98.7	97.9	67	63	18	18
36.	96°-93°	18 v.	97.9	98.1	71	92	26	38
37.	93°-91°	18 v.	97.5	97.5	61	62	19	20
38.	95°-92°	15 v.	98.8	98.6	74	96	30	32
39.	96°-93°	15 v.	99.2	98.8	68	80	22	22
40.	96°-95°	14 v.	99.7	99.7	106	98	24	30
41.	96°-94°	9 v.	99	98.6	78	96	22	18
42.	97°-94°	12 v.	99.1	98.9	76	84	18	18
43.	95°-93°	12 v.	99.1	99.1	72	80	19	18
44.	96°-94°	13 v.	99	98.7	68	90	18	21
45.	94°-91°	10 v.	98.3	98.3	72	69	22	20

No. of Bath	Temperature of Water.	Strength of Current.	Temperature. Before	After	Pulse Before	After	Respirations. Before	After
46.	93°-90°	rising to 12 v.	98.9	98.5	69	84	20	21
47.	93°-91°	10 v.	99	98.8	72	80	18	18
48.	97°-95°	10 v.	98.2	98.7	84	82	22	22
49.	96°-94°	15 v.	98.5	98.5	80	100	15	15
50.	96°-94°	16 v.	98.4	97.4	63	62	24	20
51.	97°-95°	15 v.	99.8	99.6	120	100	26	22
52.	93°-90°	10 v.	99.1	98.8	72	84	18	20
53.	97°-94°	17 v.	97.9	97.2	79	104	16	15
54.	98°-96°	12 v.	98.6	98.3	70	82	18	22
55.	98°-96°	17 v.	99.2	99	118	104	30	26
56.	96°-94°	16 v.	98	98.2	85	100	14	16
57.	97°-95°	15 v.	99.9	99.5	128	109	28	25
58.	96°-93°	15 v.	99.2	99.1	106	108	22	22
59.	97°-94°	13 v.	98.7	98.5	115	122	24	25

Examining these figures more closely it is evident that the patients' temperature has risen on 14 occasions after taking the bath, has fallen on 36 occasions, and has 9 times remained stationary.

On 39 occasions the temperature of the water of the bath was, at the conclusion, below 95° and on 27 of those occasions the patients' temperature was lower, on 7 it was found to have remained stationary and on 5 occasions it was higher.

Of 20 baths in which the water at the end was above 95° the patients' temperature was raised on 9 occasions, remained stationary on 2, and was lowered on 9.

Thus, of the series of 59 baths the water was on 39 occasions at a temperature below 95° and on 20 occasions above 95° while the patients' temperature fell on 36 occasions and rose on 14.

These facts, therefore, would seem to point to the conclusion that in the main the effect on the temperature was due to the temperature of the water. Of the results contrary to what one would have expected in this respect, namely, the 5 occasions on which the temperature rose in a bath of under 95° and the 9 occasions on which it fell in a bath of over 95° it would seem that no important deduction could be drawn.

On 9 of those occasions the change of temperature was one towards the normal, while on 5 occasions it was away from it.

On the whole it is impossible to conclude from the figures that there was any immediate electric effect on the patients' temperature apart from the effect of the warm bath and apart from what one may term personal idiosyncracy in reaction.

On 42 occasions out of the 59 the pulse was found to be quickened, in 2 cases it remained stationary and on 15 occasions it was diminished in frequency.

Of the 42 occasions on which it was quickened the temperature of the water at the conclusion of the bath was on 13 occasions above 95° and on 29 occasions below that figure, while of the 15 occasions on which it was slowed the water on 2 occasions was above 95° on 5 occasions was 95° and on 8 occasions was below 95°.

Apparently, therefore, there was little or no relation between the temperature of the water and the effect on the pulse-rate.

As regards the effect of the strength of current on the pulse rate:-

Pulse-rate.	Current over 15 volts	Current 15 volts.	Current under 15 volts.	No.
increased 42 times	16	10	16	42
diminished 15 "	2	7	6	15
stationary 2 "	0	1	1	2

Strength of current.	No. of Baths.	Pulse increased.	Pulse-rate diminished	Pulse-rate stationary.
over 15 v.	18	16	2	0
15 v.	18	10	7	1
under 15 v.	23	16	6	1

Thus in 88.9% of baths of a voltage over 15 the pulse-rate was increased, while in 69.6% of baths of a voltage under 15 the pulse-rate was increased; from which it would appear that the tendency to increased pulse-rate was more marked the stronger the current employed.

Now, does this change in the pulse-rate - this tendency to increase - show any tendency to a closer approximation to a normal rate? I shall take it that a normal pulse-rate is one from 70 to 85 beats per minute. Excluding cases in which the pulse-rate remained stationary I find that in 17 cases there was a tendency towards a more normal pulse-rate, in 11 cases both records were within the limits I have mentioned, while in 29 cases there was a deviation from the normal.

Of these 29 cases, 12 were in cases of baths of voltage over 15, 9 were of voltage 15 and 8 were under 15 volts, and thus with the stronger currents there was a greater tendency to deviation from the normal, in every one with one exception of the 12 baths of strongest current the deviation being in the manner of increased pulse-rate. Thus, while the stronger currents show the greatest tendency to increase the pulse-rate, this increased pulse-rate is an aberration from the normal.

Now, is this tendency to effect a quicker pulse-rate, specially in the cases where stronger currents are employed, to be considered due to the action of the electric current? Can one definitely say that the result of 15 minutes administration of the sinusoidal current is to quicken the pulse-rate? Looking to the former figures as regards the results on a healthy person the reverse is apparently the case and in addition in cases of treatment such as that at present under consideration, outside factors have to be taken into account. Many of the patients subjected to treatment are of an excitable nature, all are under par and consequently more liable to variations from the normal than if healthy. In addition, such a novel plan of treatment is nearly always, in the beginning, viewed with feelings of distrust and apprehension, which frequently are never entirely removed.

Electricity is regarded as a potent factor for good or for evil and, while hoping for the good results, the patient frequently cannot divest his mind of fears of evil. With such varied mental impressions affecting him it seems impossible not to expect some slight effect on such a readily affected condition as the pulse-rate, and, consequently, I fail to see that it is possible to draw any conclusive deductions from the above figures as to the effect peculiar to the sinusoidal current on the pulse-rate.

Taking the figures as regards the respiration, I find that on 31 occasions was the rate increased at the end of the bath, on 16 occasions it remained stationary, and on 12 occasions it was diminished.

Of the 31 occasions on which it was increased, on 27 of these was the pulse-rate also increased, while of the 12 occasions on which it was diminished, on 7 of these was the pulse also found to be slower, while on 5 it was faster. Here also, therefore, as in the case of the pulse, is evident a distinct tendency to quickening of the respiration-rate as a result of the bath, the two results tending, in the main, to go hand in hand, while at the same time, the respiration would appear to be affected to a rather less extent than the pulse, as evidenced by the 16 occasions on which it remained stationary, compared with the 2 occasions in the case of the pulse.

Looking now to the separate cases.

Case I. - Female, Neurasthenia, 10 baths.

Bath	Temperature of Water.	Strength of Current	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1st	96^{o}-94^{o}	rising to 9 v.	99	98.6	78	96	22	18
3rd	95^{o}-93^{o}	12 v.	99.1	99.1	72	80	19	18
4th	96^{o}-94^{o}	13 v.	99	98.7	68	90	18	21
5th	93^{o}-90^{o}	12 v.	98.9	98.5	69	84	20	21
6th	93^{o}-91^{o}	10 v.	99	98.8	72	80	18	18
7th	93^{o}-90^{o}	10 v.	99.1	98.8	72	84	18	20
9th	98^{o}-96^{o}	12 v.	98.6	98.3	70	82	18	22

This patient was an elderly woman of 65, who, for the past year or two had suffered much trouble and worry in her private life. She was a well-educated, well-read, sensible person, but with a certain melancholic tendency. For the past couple of months she had been complaining of a numb sensation and pain, extending from the right shoulder down the arm, with weakness of the arm. Sleeplessness was also complained of. On examination she was found to be a well-nourished woman and no abnormalities were to be made out. Electric examination showed the motor and sensory phenomena to be normal. Besides treatment with the sinusoidal baths, she also had daily local application of a galvanic current to the arm.

Each time after treatment with a bath the pain was lessened, but, apparently, only temporarily, as on several occasions after an improvement for several hours, the pain returned as severe as formerly. Thus no marked permanent improvement in the pain complained of was noted, but, on the other hand, the baths appeared to have a distinct influence on the patient's general sense of well-being, and she frequently referred to her improved general condition.

Case II. - Female, Neurasthenia, 8 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature.		Pulse		Respirations	
			Before	After	Before	After	Before	After
5th.	95°-92°	rising to 17 v.	98.5	98.8	92	100	18	20
6th.	99°-96°	20 v.	98.6	98.4	100	108	20	21

This was the case of a highly excitable woman who complained of sleeplessnes, loss of appetite, headache, pains in her stomach and back and general feeling of debility.

She was able to stand a fairly strong current and improved under the treatment in every way, feeling always very much "refreshed" after a bath.

Case III. - Male, Neurasthenia, 4 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature. Before	Temperature. After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1st.	96°-94°	rising to 15 v.	98.5	98.5	80	100	15	15
3rd.	97°-94°	17 v.	97.9	97.2	79	104	16	15
4th.	96°-94°	16 v.	98	98.2	85	100	14	16

Patient - a musician - was an exceedingly neurasthenic young man and was always very excited in the bath. He said he had been working hard and had felt ill for 9 months, complaining specially of general weakness and pains throughout the body. He apparently had not led a very steady life and he was very excitable. He slept very badly. He declared that he felt stronger after a bath and generally in an improved condition. The pains were greatly lessened and he slept much better. After 4 baths, however, he left Hospital.

Case IV, - Male, Sciatica, 6 Baths.

Bath	Temperature of Water	Strength of Current.	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1st.	98°-96°	rising to 7 v.	98.6	99.8	96	88	24	24
2nd.	94°-91°	15 v.	98.4	97.8	112	104	24	22
3rd.	97°-95°	15 v.	99.1	98.2	104	84	28	23
4th.	95°-93°	15 v.	99	97.8	82	70	24	24

Patient aet. 41, had had malaria off and on for 15 years. The pain complained of was chiefly high up the leg in the course of the sciatic nerve and he had been treated for it in various ways for the past three months, but with no good effect,

At the first bath he was unable to bear much strength of current and he said the pain was increased.

After the bath he was considerably cyanosed and very shivery and didn't feel well for several hours. After the 2nd bath he again was blue and shivery, but not so bad as the first time and after the 3rd bath it was still less marked.

After 6 baths, however, as they were evidently not benefitting him at all, they were discontinued.

Case V, - Male, Sciatica (double), 6 Baths.

Patient aet. 48, had suffered from sciatica for years previously, for which he had been treated with drugs, cautery, blisters, needling, without benefit.

As a result of the baths he found that the pain was relieved temporarily. After each bath he was comparatively free of pain till the following morning, when it returned as severe as previously, till the taking of the next bath.

Case VI, - Female, Hysterical paraplegia, 8 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1st.	96°-95°	rising to 14 v.	99.7	99.7	106	98	24	30
2nd.	97°-95°	15 v.	99.8	99.6	120	100	26	22
4th,	98°-96°	17 v.	99.2	99	118	104	30	26
5th.	97°-95°	15 v.	99.9	99.5	128	109	28	25
6th.	96°-93°	15 v.	99.2	99.1	106	108	22	22

This patient, a girl of 24, was very excitable and always particularly nervous before taking the bath.

There was little or no improvement in her condition as a result of the baths which apparently did not affect her at all.

Case VII, Female, Rheumatoid arthritis, 16 Baths.

Bath	Temperature of Water	Strength of Current.	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations Before	Respirations After
5th.	98°-96°	rising to 15 v.	97.6	98	92	100	25	25
6th.	100°-98°	18 v.	99.8	100	88	99	24	26
7th.	95°-92°	17 v.	98.8	99.1	74	90	28	26
8th.	99°-97°	15 v.	99	99.4	72	105	22	28
10th	97°-96°	20 v.	99.3	99.5	94	108	22	29
11th	99°-97°	18 v.	99.2	99.4	84	105	22	24
13th	99°-97°	20 v.	98.8	99	79	105	18	26

This patient, aet. 34, was so crippled from rheumatoid arthritis as to be unable to walk. The upper extremities were also seriously affected and she experienced great pain on attempts at movement. In addition to the baths, she was also regularly massaged. She had been ill for over a year and had visited numerous health-resorts and undergone treatment at them, all with no effect.

Very nervous about the baths to begin with, she almost immediately began to realise that benefit was accruing from them.

After her 6th bath her knees were so much more supple and less painful that she was almost able to walk, and after the 7th, it was noted that whereas formerly it had been quite impossible for her to straighten her legs in bed, she now could do so.

Her general sense of well-being increased and the pain was considerably diminished.

After the 16th bath she was able to walk a little very gingerly and her joints were considerably less stiff, while pain was almost entirely absent.

To begin with she had been very depressed and hopeless as to her condition, but, gradually, this feeling of depression passed away and she became, on the contrary, very hopeful.

Case VIII, - Male, pseudo hypertrophic Paralysis, 20 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature. Before	Temperature. After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1st	98°-96°	rising to 10 v.	98.9	99.2	78	80	48	40
3rd	94°-92°	15 v.	98.2	98.2	88	92	32	36
5th	94°-93°	14 v.	98.2	98.2	68	80	28	28
8th	93°-91°	10 v.	98.2	98.2	70	84	27	32
9th	97°-96°	12 v.	98.2	98.2	68	94	30	32
16th	96°-94°	11 v.	98.1	98	65	90	27	36
17th	95°-92°	15 v.	98.5	97.9	80	77	24	34

Case VIII. Continued.

Bath	Temperature of Water.	Strength of Current.	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations Before	Respirations After
18th	96°-94°	rising to 17 v.	98.1	97.8	64	90	30	32
19th	96°-93°	18 v.	97.9	98.1	71	92	26	38
20th	95°-92°	15 v.	98.8	98.6	74	96	30	32

Patient had previously been treated for 8 weeks by massage, gymnastics, etc., and was improving slightly.

At the time of commencement of the baths the gait was characteristically waddling and the patient rose from the recumbent position by climbing up his knees.

The muscles of the calf were markedly increased in size.

After the 3rd bath patient mentioned that he felt sure baths were doing him good as he felt much stronger afterwards. He was gaining in weight and walking markedly better.

In the course of the baths the circumference of the calves diminished by over an inch and at the end he could rise naturally from the floor and his gait was not markedly abnormal.

Case IX, - Male, Neuromata, 6 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature Before	Temperature After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
4th	92°-90°	rising to 20 v.	98	98.2	70	72	16	18
5th	96°-94°	20 v.	98.1	97.8	65	75	18	18
6th	97°-95°	20 v.	98	97.6	68	82	18	18

Nearly three years previously, patient had an accident and his hand had in consequence to be amputated. Two more inches of the arm were removed a year ago, and five weeks afterwards, neuromata appeared, which were three times removed without avail. He came complaining of great pain in the stump.

While in the bath he felt the pain very severely in the stump, but, afterwards, it was always, for a few hours, very much less. There was, however, no lasting benefit.

The patient always felt sick and giddy after a bath.

Case X, - Male, Chlorosis, 8 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature. Before	Temperature. After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
4th	95°-93°	rising to 15 v.	99	98.6	100	100	24	26
5th	94°-92°	15 v.	98.7	98.2	110	114	16	20
6th	94°-92°	13 v.	98.8	98.2	104	120	14	18

Patient, aet. 15, had suffered from anaemia all his life. He was under treatment as well with iron and cod-liver oil and both the number of red corpuscles and haemoglobin in his blood were steadily improving. This improvement continued while under treatment with the baths, but was not, apparently, any more rapid, though he said the baths always made him feel better and as if he had had a tonic.

Case XI, - Female, muscular Rheumatism, 6 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature. Before	Temperature. After	Pulse Before	Pulse After	Respirations. Before	Respirations. After
1st	94°-91°	rising to 11 v.	99.2	98.8	94	89	17	18
2nd	96°-93°	11 v.	98.8	98.1	75	75	18	18
3rd	96°-93°	13 v.	98.7	97.9	67	63	18	18
5th	96°-93°	15 v.	99.2	98.8	68	80	22	22
6th	97°-94°	12 v.	99.1	98.9	76	84	18	18

This was a case of what was apparently muscular rheumatism in the adductors of the thigh. There was no other treatment and the baths had no beneficial effect.

Case XII, - Male, Lumbar Pain 4 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature.		Pulse		Respirations.	
			Before	After	Before	After	Before	After
1st	94°-91°	rising to 10 v.	98.3	98.3	72	69	22	20
3rd	96°-94°	16 v.	98.4	97.4	63	62	24	20

Six months previously patient, aet. 50, had suffered a strain of the back owing to a mine accident. Previous treatment by cautery, blister, etc., had done little or no good. He complained of constant aching pain in the lumbar muscles sufficiently severe to cause sleeplessness. As a result of the baths he found that for the remainder of the day after each bath he suffered very much less pain and had a good night's sleep, but that early the following morning the pain returned as bad as previously.

Case XIII, - Male, chronic hypertrophic pulmonary ostes-arthropathy, 8 Baths.

Bath	Temperature of Water.	Strength of Current.	Temperature.		Pulse		Respirations.	
			Before	After	Before	After	Before	After
4th	90°-89°	rising to 15 v.	97.3	97.2	62	60	18	20
5th	94°-92°	21 v.	97.5	97	54	62	20	22
6th	97°-95°	15 v.	98.4	97.9	68	78	20	20
8th	93°-91°	18 v.	97.5	97.5	61	62	19	20

Patient, aet. 72, seemed to be refreshed by the baths and said that he felt much better and more supple always afterwards.

3. Treatment of Sick Children.

The method of administration of the current in these cases was as follows:-

Generated by a dynamo in the Institution, an electric current of 105 volts .8 ampere was obtained.

This current was led through a large resistance shunt to a small electro-magnetic machine similar to that described by d'Arsonval from which in turn the alternating current was conducted to the electrodes in the bath. Neither the voltage nor the amperage of the current could be gauged with certainty, the means of regulating the flow being the resistance shunt.

The bath was of insulating material and one large uncovered metallic electrode was used at each end of the bath. The voltage, probably, in no case exceeded 7 or 8 volts, but the regulation of the current was guided purely by the sensations produced by the water and the reaction of the child to it. The child was placed in the centre of the bath between the two electrodes but in contact with neither and the duration of each bath was 10 minutes.

7 patients were treated and 60 baths administered.

Case 1.	Infantile Paralysis,	16 Baths.
" 2.	Do.	9 "
" 3.	Do.	10 "
" 4.	Do.	6 "
" 5.	Do.	5 "
" 6.	Do.	4 "
" 7.	rickets	10 "

Thus of the 7 cases treated, 6 were cases of infantile paralysis and 1 was a case of rickets.

Case I.

Duration of paralysis 19 months - marked atrophy of the limb, patient otherwise in good health. Reaction of muscles of affected limb to faradism and galvanism normal in character but weak.

As a result of treatment no improvement whatever.

Here the absence of an abnormal electric reaction was probably due to the fact that all the affected muscular tissues being entirely atrophied only the remaining unaffected muscle responded.

Case II.

Duration of paralysis 21 months.

Patient was in Hospital for a fortnight at the date of onset but since then had no treatment at all.

The limb had gradually become weaker and more limp and the general health of the patient was poor.

Markedly weak re-action of the muscles of the affected limb to both galvanism and faradism - no reaction of degeneration. The limb was constantly cold and bluish.

After the course of baths there was apparent an undoubted improvement in the child's general condition and as regards the affected limb, although there was not the slightest improvement of the paralysis, the circulation was greatly improved and the limb much warmer than formerly had been the case.

Case III.

This was a case of 5 months duration with a certain degree of wasting and marked powerlessness of the limb affected. Weak reaction of affected muscles to both galvanism and faradism.

As the result of a course of 10 baths considerable improvement was evident. The paralysis steadily improved, the electric re-action of the limbs on either side became similar.

Case IV.

18 months since onset of paralysis and limb has constantly been getting worse - otherwise health fairly good. Electric examination of affected limb showed weak re-action to galvanism and faradism.

As a result of treatment no improvement whatever.

Cases V. and VI.

These cases were similar to No. IV, the

paralysis having lasted over 18 months in both and treatment producing no improvement at all.

Of these 6 cases of infantile paralysis, 5 were thus of a duration of 18 months and over, while 1 was under 6 months.

In 4 out of the 5 cases of lengthy duration no improvement whatever was marked, while in the remaining 1 (Case II.) where the child was to begin with in poor health otherwise, a certain amount of improvement was noted.

In the case of No. III. of 5 months duration during the 5 weeks' treatment by baths steady improvement was noted.

Case VII.

A case of rickets in a child three years old.

There was marked weakness of the limbs, more particularly of the legs with inability to walk. Electrical reactions normal.

The child had been for some weeks under treatment with cod-liver oil emulsion and was slowly becoming stronger. After the commencement of bath treatment the gain in weight became more rapid and at the close he was commencing to walk.

CONCLUSIONS.

A review of the cases previously cited, leads one to conclude that in lowered states of the system a certain amount of general tonic effect is to be expected from the administration of sinusoidal baths, that pain is alleviated and sleep induced.

In cases of neurasthenia, muscular dystrophy, sciatica, rheumatoid arthritis, and rickets marked improvement was noted as a result of treatment, while in cases of infantile paralysis, apart from a tonic influence in cases of general debility, no improvement whatever was manifest in old standing cases, while beneficial results were seen in a case of under 6 months duration, where the electric reactions were diminished quantitatively but not qualitatively.

The extent to which the beneficial result is due to the sinusoidal form of the current is rather difficult to estimate.

Doubtless administration of electricity by means of a bath is a comparatively agreeable form of treatment and particularly in the case of children peculiarly suitable. It is not, however, a method which lends itself readily to an exact discrimination between the effects produced by different electric currents.

That the general effects produced by a course of sinusoidal baths are tonic, with a certain sedative effect on pain, and, consequently, improved sleep, seem to be the outstanding facts.

There can be no doubt, however, that in many cases, the pyschical effect is one of the most important factors to be considered.

The effect of a novel form of treatment on impressionable persons must be always borne in mind, and while probably usually raising bright hopes of improvement in them, the resulting good done may, in many instances, largely depend on the perfect belief or otherwise of the medical man in his method of treatment and the consequent confidence or lack of confidence in the ultimate result which he imparts to his patient.

R E F E R E N C E S

Balfour Stewart	. Physics.
Joubert, Foster and Atkinson .	. Electricity and Magnetism.
Bordier . .	. Précis d'Electrothérapie.
Steavenson and Lewis Jones .	. Medical Electricity.
De Watteville .	. Medical Electricity.
Wilhelm Erb .	. Electro-therapeutics.
Bigelow . .	. An international System of electro-therapeutics.
Goldscheider and Jacob . .	. Handbuch der Physikalischen Therapie.
Humboldt . .	. Sur le Galvanisme.
Bois-Reymond .	. Untersuchungen über Thierische Elektricität.
Meyer . .	. Die Elektricität.
Duchenne . .	. De l'electrisation.
Von Ziemsson .	. Handbook of General Therapeutics.
Rockwell . .	. Medical and Surgical Electricity.
Von Corval and Wunderlich .	. Das elektrische Bad. Deutsche Med. Wehnschr. 1884 X 325.
Gaertner (G.) .	. Uber elektrische Medicinalbader. Wien klin. Wehnschr. 1893 VI. 606.

Trautwein (J.) . Uber das Verhalten des Pulses, der Respiration und des Körper temperatur im elektrischen Soolbade. Deutsches Archiv. f. klin. Med. Leipz. 1887 XLI. 261.

Cohen . . . System of physiologic Therapeutics.

Hedley . . . Hydro-Electric Methods in Medicine.

D'Arsonval . . Archives de Physiologie, 1889-93.

Gautier and Larat . Gazette des Hôpitaux, 1895.

Kellog . . . International System of Electrotherapeutics, Bigelow.

Kaplan-Lapina . . Du Courant Alternatif Sinusoidal en Gynécologie.

Cohen . . . System of Physiologic Therapeutics.